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Demand and Substitution of Agricultural Inputs in the Central Corn Belt States

Jorge Fernandez-Cornejo

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Demand and Substitution of Agricultural Inputs in the Central Corn Belt States.
By Jorge Fernandez-Cornejo. Resources and Technology Division, Economic Research Service, U.S. Department of Agriculture. Technical Bulletin No. 1816.

Abstract

This study estimates shortrun and longrun elasticities for agricultural inputs, along with elasticities of substitution, using a theoretically consistent restricted profit function and a series of decomposition equations. The model is also disaggregated on the input side, uses a flexible functional form, incorporates the effect of agricultural policies, and introduces a weather index. The methodology is applied to the central Corn Belt States and is used to calculate the effect of market-oriented policies to reduce chemical input use. The study finds that producers' responsiveness to price changes of fertilizer and pesticides is very small in the short run and moderate in the long run. Ad valorem taxes would have negligible shortrun and small longrun effects on chemical input use while restructuring Federal programs appears to be effective in the long run.

Keywords: Input demand, input substitution, decomposition methods, imposing curvature conditions, shortrun and longrun elasticities, chemical inputs.

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Jorge Fernandez-Cornejo

Introduction

Measuring the ease of substitutability between production factors is of practical and theoretical importance in economics. Many pessimistic predictions of natural resource depletion have proved to be grossly incorrect because the models proposed failed to recognize important substitution relationships (Field and Berndt). Concerns over the environmental and health effects of agriculture have intensified the interest in issues of input substitution and thus call for quantitative assessments of the effects of changing (input/output) market conditions and of government policies on the demand for agricultural inputs.

Assessing those policy alternatives intended to limit the use of fertilizers and pesticides (chemical inputs) is particularly important. The intensification of agricultural production made possible by chemical inputs can also contribute to the contamination of ground and surface water resources and to the presence of toxic residues in food. Environmental and human health costs associated with the use of chemical inputs are not fully reflected in the decisions of individual farmers. Because individual farmers do not bear the full costs of the negative effects that occur off the farm, there may be a tendency to overuse the chemical inputs. This situation was exacerbated in U.S. agriculture by government policies and programs which, particularly in the past, have tended to support output prices and restrict land use (Miranowski).[1] Consequently, an analysis of policies to reduce the use of these chemical inputs to improve water quality and food safety should include the effect of government agricultural price supports on chemical input use.

Two major approaches could be considered to reduce the application of chemical inputs in a targeted area. These are the regulatory approach (such as banning specific pesticides) and the economic approach. But, as Miranowski observes, the regulatory approach has serious limitations because it does not modify the "underlying economic forces" that motivate farmers to apply chemical inputs. Two relatively simple economic strategies are the imposition of ad valorem taxes on chemical inputs and the reduction of government price supports for agricultural output.[2] The effectiveness of such strategies depends on the responsiveness of the input demand to increases in input prices and to the decreases in the output price expected by farmers.

The failure of many econometric models to incorporate substitution possibilities is due partly to lack of reliable information on price elasticities of input demand. Published empirical estimates of input

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[1]However, the 1985 Food Security Act and the 1990 Food, Agriculture, Conservation and Trade Act have reduced these effects and made their causation less direct.

[2]Sweden, Austria, and Finland currently impose a 25-percent tax on nitrogen and phosphorus fertilizers (OECD). Iowa has a very small (less than 0.5-percent) tax on nitrogen fertilizers for the purpose of raising revenue for research and extension activities related to groundwater protection.

Table 1—Input demand elasticities: Selected empirical studies in agriculture

Author, year, country or State	Type of demand	Functional form	Number of outputs /variable inputs/ quasi-fixed inputs	Curvature imposed?	Allowance for weather/government policy
Binswanger, 1974, USA[1]	Hicksian, long run	Translog	1/5/0	no	no
Lopez, 1980, Canada[1]	Hicksian, long run	Generalized Leontief	1/4/0	no	no
Ray, 1982, USA[1]	Hicksian, long run	Translog	1/5/0	no	no
Brown-Christensen 1981, USA[1]	Hicksian, short run/long run	Translog	1/3/2	no	no
Capalbo M2, 1988, USA[1]	Hicksian, long run	Translog	1/4/0	no	no
Capalbo M4,[2] 1988, USA[1]	Hicksian, long run	Translog	2/5/0	no	no
Weaver, 1983, ND	Marshallian, short run	Translog	3/5/1	no	yes
Shumway, 1983, TX	Marshallian, short run	Normalized quadratic	6/3/2	no	yes
Lopez, 1984, Canada[1]	Marshallian/ Hicksian, long run	Generalized Leontief	2/4/0	no	no
Antle, 1984, USA[1]	Marshallian, long run	Translog	1/4/0	no	no
Capalbo M7, 1988, USA[1]	Marshallian, short run	Translog	1/3/1	no	no
Ball, 1988, USA[1]	Marshallian, short run	Translog	5/6/1	yes	no
McIntosh-Shumway, 1989, CA	Marshallian, short run	Normalized quadratic	10/4/3	yes	yes
Burell, 1989, U.K.[1]	Marshallian/ Hicksian, short run	Translog	6/3/3	no	no

[1]Country aggregates.
[2]The numbers refer to models 2, 4, and 7 (M2, M4, and M7) appearing in Capalbo (1988).

demand elasticities in U.S. agriculture vary widely (tables 1 and 2), even when earlier estimates based on ad hoc models are excluded. To a large extent, the differences among elasticity estimates are due to differences in model specification, including levels of aggregation of inputs/outputs and firms, functional form, price expectations, and introduction of exogenous variables (for example, weather or government policy). Elasticity estimates may also differ because of differences in behavioral assumptions, such as profit maximization or cost minimization. Finally, many reported elasticities may be unreliable because they are often derived from models that are inconsistent with economic theory and frequently use unrestricted cost or profit functions, which implicitly assume longrun equilibrium.

That analyses of agricultural production structure should be carried out on a State (or county) level has become increasingly evident. Shumway and Alexander and Huy, Elterich, and Gempesaw, as

Table 2—Own-price elasticities of input demand: Selected estimates in agriculture

Author/year	Hired labor	Fertilizer	Chemicals
Binswanger, 1974	-0.911	-0.945	NA
Lopez, 1980	-.897[1]	NA	-0.391
Ray, 1982	-.839	-.128	NA
Brown-Christensen, 1981	-.650	NA	-.188
Capalbo M2, 1988[3]	-.207[1]	NA	-.688
Capalbo M4, 1988[3]	-.492[1]	NA	-.876
Weaver, 1983	-1.016[1]	-1.377	NA
Shumway, 1983	-.430	-.700	NA
Lopez, 1984	-.377/-1.24[2]	NA	NA
Antle, 1984	-1.311	NA	-.194
Capalbo M7, 1988[3]	-.594[1]	NA	-.606
Ball, 1988	-1.500	NA	NA
McIntosh-Shumway, 1989	-.593	-.038	NA
Burell, 1989	NA	-.420	NA

NA = Not available (input not reported as a separate category). [1]Includes hired and family labor. [2]Hicksian/Marshallian elasticities. [3]The numbers refer to models 2, 4, and 7 (M2, M4, and M7) appearing in Capalbo (1988).

well as others, have documented very large differences in the production structure among agricultural regions. Recent empirical studies have found that the structure of production varies even among States of the same production region (Polson; Lim and Shumway, 1989b). Furthermore, the environmental effects of agriculture vary widely across regions. In particular, the regional distribution of the potential for groundwater contamination from nitrates and pesticides is uneven across the country. Contamination is particularly serious in areas with high application rates of nitrogen or mobile pesticides,[3] shallow water tables, and permeable, coarse-textured soils (Miller). Of the Nation's 3,000 counties, about 300, located chiefly in the upper Midwest and East, have been identified as having the potential for contamination of ground water by both nitrates and pesticides (Lee).

Objectives and Methodology

This paper has two objectives. First, it sets out to determine theoretically consistent Hicksian and Marshallian input demand functions and elasticities of substitution (ES) in the short and long run. The second objective is to use these models to simulate the imposition of ad valorem taxes on chemical inputs and the reduction of Federal agricultural output supports and to compare the effect of these two alternatives on chemical input use. Shortrun (SR) Marshallian demand functions are calculated directly using a restricted profit function. Longrun (LR) Marshallian and SR Hicksian demands are derived next via decomposition equations. Finally, LR Hicksian demands are calculated from the SR Hicksian demands by a second transformation. Altogether, this decomposition technique provides a total of four types of demand functions which, if estimated directly, would require estimation of two cost functions and two profit functions. This decomposition also makes possible the calculation of SR and LR elasticities of substitution (which are based on Hicksian demand functions) while maintaining the assumption of profit maximization. The estimated input demand functions are used to simulate two market-oriented strategies intended to reduce the use of chemical inputs in agriculture.

[3]About 30 percent of the fertilizers and 28 percent of the pesticides were applied to less than 13 percent of the U.S. agricultural land in the central Corn Belt in 1988.

Economic theory requires the restricted profit function to be convex in prices and concave in quasi-fixed factors. Convexity in prices has been imposed by Ball, by Shumway and Alexander, and by others. However, unlike this study, previous researchers have not simultaneously imposed convexity in prices and concavity in quasi-fixed factors. Both curvature properties are essential, particularly when using decomposition methods. While convexity in prices ensures that SR Marshallian elasticities are of the "correct" sign, Le Chatelier's principle may be violated if the restricted profit function is not concave in quasi-fixed inputs. For example, some LR own-price elasticities may be smaller (in absolute value) than corresponding SR elasticities, and own-price Hicksian elasticities may be larger than corresponding Marshallian elasticities. Among the few decomposition studies in agricultural economics, Lopez (1984) and, more recently, Higgins use a longrun profit function to derive LR Hicksian elasticities. In both cases, the convexity requirement is violated. Hertel uses a restricted profit function to obtain shortrun and longrun Marshallian elasticities. Convexity in prices is satisfied in Hertel's model using pseudodata, but the issue of concavity in quasi-fixed factors does not arise because Hertel considers only one quasi-fixed factor and assumes constant returns to scale.

The empirical model in this paper uses a Fuss-quadratic normalized restricted profit function and is disaggregated in the input side to a larger extent than in previous dual models. For example, feeds, seeds, fertilizer, pesticides, fuels, hired labor, and family labor are each a separate category. In addition, the model allows for the effect of Federal agricultural programs and policies on farmers' price expectations, and a new weather index is introduced. This paper reports empirical results for the central Corn Belt States (Indiana and Illinois), which have a large potential for both nitrate and pesticide contamination of ground water (Lee). However, the methodology developed in this paper may be used on similarly exposed areas.

Hicksian and Marshallian Elasticities

The neoclassical theory of the firm is based on the optimizing behavior of producers subject to some constraint (for example, a production or transformation function). Input demand and output supply functions may be obtained after solving explicitly an optimization problem by using the first order conditions. This primal approach can be very involved except for simple functional forms, such as the Cobb-Douglas, which impose arbitrary restrictions on the production technology (like additivity and limited substitution possibilities). In addition, the econometric estimation of primal models is not very reliable because of simultaneous equation bias and multicollinearity among input quantities.

Duality theory allows the determination of supply and demand functions without explicit solution of the optimization problem, making possible the use of flexible functional forms with maintained hypotheses weaker than in traditional primal methods, thus increasing the generality of the inference (Gallant and Golub).[4] Dual models require some behavioral assumptions about the firm and the market where it operates. In agriculture, it is usual to assume cost-minimizing or profit-maximizing firms operating in competitive markets. The choice of the dual model (for example, a cost or profit function) has an important effect on the input demand and output supply functions directly derived from the model. If a cost function approach is used, input demands obtained from Shephard's lemma are characterized as conditional on output level. These Hicksian (or compensated) input demands reflect movements along an isoquant (Sakai; Lopez, 1984) and are often used to calculate elasticities of substitution. When a profit function model is specified, the unconditional input demands obtained from application of Hotelling's lemma are the Marshallian demands, also known as uncompensated or ordinary demands. Marshallian demands include substitution effects along the old isoquant and expansion effects along the expansion path (to the new isoquant).

[4]Multicollinearity is also likely to be less severe among factor prices required in the dual approach than among factor quantities used in primal methods, and the exogeneity of factor prices is more likely to hold.

A version of Le Chatelier's principle requires own-price Marshallian elasticities to be larger in absolute value than the corresponding Hicksian elasticities because the latter hold output (as well as all other prices) constant, while Marshallian elasticities allow both inputs and outputs to adjust to their new equilibrium levels. A procedure similar to Slutsky's decomposition may be applied to obtain a relationship between Marshallian and Hicksian elasticities (Sakai; Lopez, 1984; Higgins).

Measures of Substitutability

The degree of substitutability between production factors is measured by the elasticities of substitution (ES). For a production process described by the production function $f(X_1,X_2)$ with two inputs X_1 and X_2 and prices P_1 and P_2, respectively, the ES (σ_{12}) is defined by the elasticity of the input quantity ratio with respect to the marginal rate of substitution between the inputs. That is, $\sigma_{12} = d\ln(X_1/X_2) / d\ln(f_1/f_2)$, with σ increasing as substitution between inputs becomes easier. Under profit maximization, the ES becomes $\sigma_{12} = d\ln(X_1/X_2) / d\ln(P_1/P_2)$. For the two-variable input, one elasticity measure suffices, since $\sigma_{12} = \sigma_{21}$ (Kang and Brown).

When more than two variable inputs are involved in production, there are as many possible definitions of ES as there are possible combinations of elements of the underlying Hessian matrix (Mundlak). Several definitions are used in the literature. The direct elasticity of substitution (DES) is an extension of the ES for two inputs, with the condition that output and all the other inputs are held constant. Because of this inflexibility, the DES is not commonly used. The Allen-Uzawa partial ES (AUES) may be expressed as the cross-price elasticity of the Hicksian input demand (ε_{ij}) divided by the respective cost share. The AUES is an example of the one-factor, one-price ES. Its popularity may be due to its appealing symmetry, although economic interpretation of cross-price elasticities is more direct (Field and Berndt).

The Morishima elasticity of substitution (MES) is classified as a two-factor, one-price elasticity of substitution and can be interpreted as the cross-price elasticity of relative demand because it measures the relative adjustment of factor quantities when a single factor price changes. If inputs i and j are net complements (their cross-price Hicksian elasticity is negative), an increase in the price P_j will lead to a decrease in the quantity employed X_i. However, since the decrease in P_j also decreases X_j, the own-price effect must be subtracted to obtain the net effect. This is what the MES represents.[5] Kang and Brown recommend the use of the MES because it has the desirable property of being invariant to the separability assumption usually made. They show that the MES does not depend on the "unestimated characteristics of the function," while a partial measure, such as the AUES, does not have this property. Thus, as Berndt and Wood find empirically, the AUES's in a three-input model may yield different values than the AUES's for a four-input model (even if the fourth input is separable). Kang and Brown also show that the calculation of MES does not even require data for omitted inputs and that values of two different studies are directly comparable.

Moreover, Blackorby and Russell (1989) show that the AUES is not a measure of the "ease" of substitutability or curvature of the isoquant, it is meaningless as a quantitative measure, it provides no additional information to that contained in the Hicksian cross-price elasticity, and it cannot be interpreted as a logarithmic derivative of an input quantity ratio with respect to a price ratio (or MRS). The MES, on the other hand, provides an exact measure of the curvature along an isoquant and may

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[5]Koizumi (1976) first suggested this interpretation. He noted that "the Morishima elasticity of substitution of X_j for X_i measures the percentage change in employment in X_i caused by 1-percent change in the price P_j of X_j after the percentage change in X_j due to pure demand effect has been partialed out." Note that the MES can be expressed as:

$$(MES)_{ij} = \partial\ln(X_i/X_j)/\partial\ln P_j = \partial(\ln X_i - \ln X_j)/\partial\ln P_j = \varepsilon_{ij} - \varepsilon_{jj}$$

be interpreted as a logarithmic derivative of an input quantity ratio with respect to an input price ratio. Consequently, the MES is a more appropriate measure of input substitution. Blackorby and Russell (1989) also note that the asymmetry of the MES is natural because, in two-dimensional input space, the curvature of an isoquant at a point is an unambiguous idea. In more than two dimensions, however, curvature may be measured in many directions. For example, the same change in the price ratio P_i/P_j may be obtained when P_j changes and P_i is held constant or vice versa. However, each case leads to a different change in the quantity ratio (X_i/X_j).

Short Run Versus Long Run

Early empirical work based on the dual framework implicitly assumes that firms are in static equilibrium. However, as Brown and Christensen observe, in many cases, the assumption of full static equilibrium "is suspect and so are the empirical results" based on these models. To relax the assumption of static equilibrium, two basic approaches are available. The first is based on the use of restricted profit or cost functions and is called a partial static equilibrium approach (Brown and Christensen) because the firm is assumed to be in static equilibrium only with the variable factors, conditional on the levels of the other factors (Gorman; Lau, 1976). The second approach uses full dynamic models within the costs-of-adjustment framework. It combines techniques of dynamic optimization and the notion of adjustment costs, which prevent instantaneous adjustment of the quasi-fixed factors. This dynamic approach differs from the restricted profit function approach because (in addition to providing estimates of shortrun and longrun demand functions) it describes the nature and the time required for the adjustment of the quasi-fixed factors. However, estimation of these dynamic models at the level of disaggregation required to examine input-substitution issues is often not feasible with available data.

Several definitions are used for the short run. Some researchers (for example, Morrison and Berndt) follow the Marshallian tradition of defining the short run as that when the stocks of the quasi-fixed factors are fixed at the current level and the long run as that when the quasi-fixed factors have fully adjusted to their desired (steady-state) levels. An alternative definition of SR elasticity can be traced to the early adjustment-lag models and is often used in macroeconomic models. In this case, the short run is longer than defined previously. It is defined as the impact when the quasi-fixed factors have adjusted partially (one-period adjustment). Friedman defines the "shortest of short runs" as that when all factors are fixed and the "longest of long runs" as that when all factors are variable (supply curves for all factors are horizontal). Intermediate lengths of run involve the adjustment of some factors in each category. Friedman adds that "which factors are to be placed in which category is to be determined by the problem at hand." This study follows the Marshallian tradition of defining the shortrun period as short enough for the stocks of the "quasi-fixed" factors to remain fixed at their current levels and the longrun period as that at which they have fully adjusted.[6]

The Restricted Profit Function

Recognition of the shortrun fixity of some production inputs makes estimation of a full equilibrium profit (or cost) function inappropriate. If the nature of the stock adjustment process is not the focus of analysis but rather the characterization of both shortrun and longrun production structure, models based on the restricted profit (or cost) function are the proper choice (Hazilla and Kopp, 1986). The theory of the restricted profit function is well developed (Gorman; Diewert; Lau, 1976). Its framework is general enough to accommodate, as special cases, cost and revenue functions and all possible intermediate cases (by allowing a subset of inputs and outputs to be variable).

[6]Short run and long run are traditionally defined in terms of inputs. However, some economists have referred to the Hicksian (constant output) demand as short run and to the Marshallian demand as long run.

This study assumes profit-maximizing producers are operating in competitive markets, and the restricted profit function is used to capture the information about the production structure in both the short and long run.[7] Consider n + m + s "commodities," including n variable net inputs/outputs (netputs), m fixed inputs/outputs, and s exogenous variables, such as time or weather. $X = (X_1 \ldots X_n)'$ denotes the vector of variable netputs, with the sign convention $X_i>0$ (<0) if the ith netput is an output (input), $Z = (Z_1 \ldots Z_m)'$ is the vector of nonnegative quasi-fixed netputs, $R = (R_1 \ldots R_s)'$ is the vector of exogenous factors, $P = (P_1, \ldots P_n)'$ is the price vector of variable netputs, and $W = (W_1 \ldots W_m)'$ is the price vector of quasi-fixed netputs. The restricted profit function is defined by:

$$\pi(P,Z,R) = MAX_X[P'X: X \in T]. \tag{1}$$

The production possibilities set T is assumed to be nonempty, closed, bounded, and convex. In addition, if Z includes only inputs, T is assumed to be a cone (Diewert; Ball). Under the above assumptions on the technology, the restricted profit function is well defined and satisfies the usual regularity conditions (Diewert). In particular, with some of the inputs fixed, π is homogeneous of degree one in variable netput prices (P) and quasi-fixed netput quantities (Z). In addition, π must satisfy symmetry (of the Hessian matrix), monotonicity, and curvature conditions. Curvature conditions require π to be convex in P for every Z and R and concave in Z for every P and R. Thus, π must be a saddle function in (P,Z) for all R. No curvature assumptions are made about R. The unrestricted profit function may be expressed as:

$$\pi(P,W,R) = Max_Z[\pi(P,Z,R) + W'Z], \tag{2}$$

where $\pi(P,Z,R)$ is defined by equation 1.

Theoretical Consistency

One of the penalties of using flexible functional forms in dual models is that the estimated functions may not be theoretically consistent because the number of parameters in a flexible form is sufficient to allow the elasticity matrix to have any value at any point in the data space (Gallant and Golub). The restricted profit function π is theoretically consistent if it satisfies the homogeneity, symmetry, monotonicity, and curvature conditions given above. Symmetry and homogeneity are usually easier to impose because they translate into equality restrictions on the parameters, which reduce the number of free parameters (the dimensionality of the parameter space). Monotonicity and curvature require inequality restrictions on the parameters, which are more difficult to impose because they reduce the parameter space but not its dimensionality; that is, they do not reduce the number of free parameters (Chalfant and White).

Dual methods require stricter curvature conditions than primal methods. As Lau (1978) notes, the production function may not be convex, but the profit function must always be convex in prices when output and input markets are competitive and firms are profit maximizers. Therefore, a nonconvex profit function is inconsistent with the behavioral assumption of profit maximization. The empirical consequences of the violation of convexity are that the signs of output supply and input demand elasticities are not consistent with economic theory and that tests of functional structure (such as separability) are meaningless because duality theorems do not apply (Hazilla and Kopp, 1985; Ball).

[7]Lim and Shumway (1989a) performed nonparametric tests for each of the 48 contiguous States using agricultural production data for 1956-82. They found "little departure" of the data from the joint hypothesis of profit maximization and a convex technology in all 48 States. They also found that, for about 90 percent of the States (including those in the Corn Belt), the data were consistent with constant returns to scale.

Imposition of curvature avoids these adverse consequences and provides a gain in statistical efficiency by using a priori information (Gallant and Golub).

The imposition of curvature frequently uses the property of a twice continuously differentiable function, which is convex (concave) with respect to a subset of its arguments if and only if its Hessian matrix is positive (negative) semidefinite.[8] Necessary and sufficient condition for the Hessian to be positive semidefinite (psd) are (1) that all the eigenvalues are nonnegative or (2) that the Cholesky values are nonnegative. This last condition provides a procedure to transform restrictions of positive semidefiniteness on the Hessian into simple nonnegativity conditions on the parameters. The procedure, used by Lau (1978), consists of setting the Cholesky values to be nonnegative. For example, the Cholesky decomposition of the Hessian H of the profit function π is $H = L^T DL$, where $H = \partial^2\pi/\partial X_i \partial X_j$, D is a diagonal matrix (the elements of which are the Cholesky values), and L is a unit lower-triangular matrix. Lau (1978) proved that the nonnegativity of the Cholesky values is a necessary and sufficient condition for positive semidefiniteness of the Hessian and, thus, for convexity.

Two basic approaches have been used to impose inequality constraints. They are the nonlinear programming/maximum-likelihood (NLP/ML) and the statistical (Bayesian) approach. The NLP/ML technique usually involves the imposition of inequalities through a maximum-likelihood estimation procedure. It was pioneered by Judge and Takayama for linear inequalities using quadratic programming methods. As better nonlinear programming algorithms, such as MINOS (Murtagh and Saunders), became available, the method was extended to nonlinear inequalities and to systems of equations and has been used empirically by Jorgenson and Fraumeni and Hazilla and Kopp (1986). In the agricultural economics literature, Shumway and Alexander, Ball, and others impose convexity in prices in a profit function using this approach. Some of the weaknesses of the NLP/ML approach stem from difficulties in the statistical interpretation of the results and inapplicability of the likelihood ratio test (Chalfant and White).

The Bayesian approach was reexamined by Kloek and van Dijk, van Dijk and Kloek, and Geweke (1986, 1989). No prior information is required beyond the inequality restrictions, which are treated as prior beliefs about the model. The Bayesian approach consists of estimating first the parameters without imposing the restrictions. If the inequality restrictions are violated, they are imposed following Geweke. For example, to impose convexity, the prior distribution is the indicator function:

$$p(\theta) = \begin{cases} 1 \; \textit{if} \; \theta \in D \\ 0 \; \textit{otherwise}, \end{cases}$$

where Θ is the parameter vector, $p(\Theta)$ its prior density function containing all information about Θ before the data are examined, and D is the set of all Θ's such that the Hessian H is positive semidefinite (that is, $D = \{\Theta \in \Re^q \mid \text{eigenvalues of } H \geq 0\}$), q is the number of free parameters, and H is the Hessian matrix. Bayes' theorem states that $f(\Theta|y)$, the posterior distribution of Θ given the data y, is proportional to the product of the prior distribution and the sample likelihood function $l(\Theta)$. The posterior contains all the available information about Θ. The mean of the posterior distribution $E(\Theta|y)$ is the value of the parameter vector Θ that minimizes expected loss for a quadratic loss function. In practice, Monte Carlo integration (Kloek and van Dijk; van Dijk and Kloek; Geweke) is used to calculate $E(\Theta|y)$, since analytical procedures are not available, and numerical procedures are too complicated beyond three or four dimensions.

Assuming, for example, that the parameter vector follows the multivariate normal distribution with a mean vector $\bar{\Theta}$ and known variance-covariance Σ, then the posterior distribution will be a truncated

[8]The alternative procedure of Gallant and Golub uses the characterizations of curvature of Diewert, Avriel, and Zang and therefore entirely avoids the Cholesky factorization procedure. However, the method requires solving two (often simpler) optimization problems instead of one. For comments about the tradeoffs between the two methods, see Hazilla and Kopp (1985).

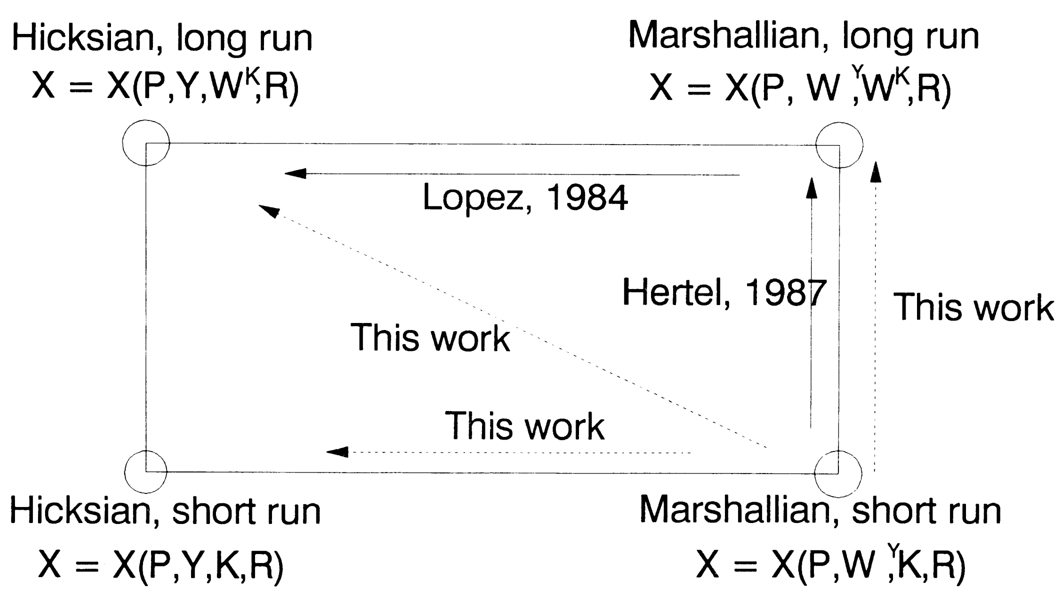
(multivariate) normal, such that Θ has nonzero values only in D. The procedure involves first estimating the unconstrained $\hat{\Theta}$ and its variance-covariance matrix by the usual procedures (for example, the iterative seemingly unrelated regression, ITSUR). Random samples are then drawn from the normal distribution and,the eigenvalues of H are calculated to verify if the particular values of Θ lie in D. All draws that yield $\Theta \notin$ D (that is, a Hessian with some negative eigenvalues) are excluded. E(Θ) is calculated from the mean of all values of Θ that are in D. Since Σ is usually unknown, the posterior is no longer multivariate normal. It is necessary to consider a joint prior p(Θ, Σ), and a technique called "importance sampling" is used (Kloek and van Dijk; van Dijk and Kloek; Geweke, 1986, 1989). The procedure indicated above is modified by sampling from a multivariate t rather than from a multivariate normal (see details in Geweke, 1986, 1989 and in Chalfant, Gray, and White). In addition to parameters, one can calculate their numerical standard errors which are "analogous to the usual standard error of the estimate of a population mean" (Chalfant, Gray, and White).

Imposition of curvature on the approximating function may be carried out either globally or locally. For example, if convexity conditions are imposed locally, there is no guarantee that the approximating function will be globally convex, except for the normalized quadratic (NQ) (Lau, 1978). Imposing global curvature often requires severe restrictions on the parameters of the approximating function that can destroy the flexibility of the functional form, leading to upward bias in the degree of input substitutability (Lau, 1978). The NQ is the only exception among traditional flexible functional forms that, if it satisfies curvature conditions locally, also satisfies them globally.

Decomposition Analysis

This section presents a series of decomposition equations required to derive all demand functions using the restricted profit function as a starting point. It is based on properties of the Hessian matrices examined first by Lau (1976) and used by Lopez (1984) and Hertel (fig. 1). If sufficient

Figure 1
Input demand/output supply functions



differentiability of the restricted profit function is assumed and the envelope theorem is used, the LR (Marshallian) net supply function is

$$[\partial\pi(P,W,R)\,/\,\partial P]_{n\times 1} = X(P,W,R). \tag{3}$$

The first order condition for longrun (full equilibrium) profit maximization from equation 2 is

$$[\partial\pi(P,Z,R)\,/\,\partial Z]_{m\times 1} = W, \tag{4}$$

which states that the shadow price vector is equal to the corresponding vector of rental prices W. From this equation, the optimum value for Z is obtained $Z^* = Z(P,W,R)$. From equation 2, using again the envelope theorem,

$$[\partial\pi(P,W,R)/\partial W]_{m\times 1} = -Z(P,W,R). \tag{5}$$

The decomposition equations of the Hessians of the restricted and unrestricted profit functions are obtained by differentiation of the above expressions with respect to P. After some algebra, the Hessian of the (unrestricted) profit function is expressed as a function of the Hessian of the restricted profit function in the neighborhood of the longrun equilibrium, as follows:

$$\begin{aligned}\left[\frac{\partial^2\pi(P,W,R)}{\partial P^2}\right]_{n\times n} &= \left[\frac{\partial^2\Pi(P,Z(P,W,R),R)}{\partial P^2}\right]_{n\times n} \\ &- \left[\frac{\partial^2\Pi(P,Z(.),R)}{\partial P\partial Z}\right]_{n\times m}\left[\frac{\partial^2\Pi(P,Z(.),R)}{\partial Z^2}\right]^{-1}_{m\times m}\left[\frac{\partial^2\Pi(P,Z(.),R)}{\partial Z\partial P}\right]_{m\times n}.\end{aligned} \tag{6}$$

The Hessian of the restricted profit function may be expressed in terms of that of the unrestricted profit function by the expression

$$\left[\frac{\partial^2\pi(P,Z(P,W,R),R}{\partial P^2}\right] = \left[\frac{\partial^2\Pi(P,W,R)}{\partial P^2}\right] - \left[\frac{\partial^2\Pi(P,W,R)}{\partial P\partial W}\right]\left[\frac{\partial^2\Pi(.)}{\partial W^2}\right]^{-1}\left[\frac{\partial^2\Pi(.)}{\partial W\partial P}\right]. \tag{7}$$

Expressing the restricted profit function in terms of a less restricted profit function is also useful. The vector of netputs held fixed in the restricted profit function is Z. Denoting the vector of fixed netputs in the less restricted profit function by Z^f with prices W^f and the vector of netputs that become variable by Z^v with prices W^v,

$$\begin{aligned}\left[\frac{\partial^2\pi(P,Z^f,Z^v,R)}{\partial P^2}\right] &= \left[\frac{\partial^2\Pi(P,W^v,Z^f,R)}{\partial P^2}\right] \\ &- \left[\frac{\partial^2\Pi(P,W^v,Z^f,R)}{\partial P\partial W^v}\right]\left[\frac{\partial^2\Pi(P,W^v,Z^f,R))}{\partial (W^v)^2}\right]^{-1}\left[\frac{\partial^2\Pi(P,W^v,Z^f,R)}{\partial W^v\partial P}\right].\end{aligned} \tag{8}$$

The LR Marshallian elasticities are expressed in terms of the corresponding SR elasticities using equation 6, noting that in the short run only some of the inputs (K) belong to the fixed netput category (Z). Using Hotelling's lemma on equation 6 yields (in derivative form)

$$\left[\frac{\partial X(P,W,R)}{\partial P}\right]^{M}_{LR} = \left[\frac{\partial X(P,K,R)}{\partial P}\right]^{M}_{SR} - \left[\frac{\partial X(.)}{\partial Z}\right]'\left[\frac{\partial^2 \pi(P,K(P,W,R),R)}{\partial Z^2}\right]^{-1}\left[\frac{\partial X(.)}{\partial Z}\right]. \tag{9}$$

Finally, to calculate the derivatives of the quasi-fixed factors with respect to price in the long run, obtaining first $Z^* = (P,W,R)$ is simpler, as shown in the next section. If the Hessian $\partial^2\pi(.)/\partial Z^2$ is negative semidefinite $[\partial X_i/\partial P_i]^{LR} \geq \partial X_i/\partial P_i]^{SR}$, which illustrates that Le Chatelier's principle will be satisfied if the restricted profit function is convex in P and concave in Z. In terms of elasticities, the above shows that LR own-price elasticities are larger (in absolute value) than the corresponding SR elasticities. The Hicksian SR input demand elasticities are obtained from equation 8, noting that in this case the fixed netputs vector Z includes all outputs (Y) and some inputs (K).[9] Thus, Z = [Y',K']'. In this case, the restricted profit function becomes $\pi(P,Z,R) = -C(P,Y,K,R)$. From equations 8 and 3, the matrix of derivatives of the SR Hicksian input demand with respect to price is

$$\left[\frac{\partial X(P,Y,K,R)}{\partial P}\right]^{H}_{SR} = \left[\frac{\partial X(P,W^Y,K,R)}{\partial P}\right]^{M}_{SR} - \left[\frac{\partial X(.)}{\partial W^Y}\right]'\left[\frac{\partial^2 \pi(P,W^Y,K,R)}{\partial (W^Y)^2}\right]^{-1}\left[\frac{\partial X(.)}{\partial W^Y}\right]. \tag{10}$$

In this expression, the first term of the right hand side is the familiar substitution effect and the second term is the expansion effect. Since $\partial^2\pi(.)/\partial(W^Y)^2$ is positive semidefinite, then $[\partial X_i/\partial P_i]^H \leq [\partial X_i/\partial P_i]^M$, which is another manifestation of Le Chatelier's principle. Finally, an expression similar to equation 10 is used to express the LR Hicksian demand after the corresponding LR Marshallian demand is obtained from an expression analogous to equation 9.

The Empirical Model

The empirical model uses the Fuss-quadratic normalized restricted profit function (Fuss; Diewert and Ostensoe). This functional form is capable of globally satisfying curvature without losing its flexibility (Diewert and Ostensoe). With symmetry and linear homogeneity in P and Z imposed, the functional form may be expressed as

$$\tilde{\Pi}(\tilde{P},\tilde{Z},R) = \frac{\Pi(P,Z,R)}{P_1 Z_1} = a_0 + (a'b'c')\begin{bmatrix}\tilde{P}\\ \tilde{Z}\\ R\end{bmatrix} + 1/2(\tilde{P}'\tilde{Z}'R')\begin{bmatrix}B & E & F\\ E' & C & G\\ F' & G' & D\end{bmatrix}\begin{bmatrix}\tilde{P}\\ \tilde{Z}\\ R\end{bmatrix}, \tag{11}$$

where $\tilde{P} = (P_2/P_1 \ldots P_N/P_1)'$, $\tilde{Z} = (Z_2/Z_1 \ldots Z_M/Z_1)'$, $R = (R_1 \ldots R_s)'$, and a_0 is a scalar parameter, while a, b, and c are vectors of constants of the same dimension as $\tilde{P}$, $\tilde{Z}$, and R. The parameter matrices B, C, and D are symmetric and of the appropriate dimensions (for example, B is (n-1)x(n-1)). Similarly E, F, and G are matrices of unknown parameters. Because no interaction is expected between exogenous factors and quasi-fixed factors, G is a null matrix, and D is diagonal. Using the envelope theorem, the vector of shortrun net supply functions divided by Z_1; that is, $\tilde{X} = (X_2/Z_1 \ldots X_n/Z_1)'$, is

$$\tilde{X}(\tilde{P},\tilde{Z},R) = \nabla_{\tilde{P}}\tilde{\pi}(\tilde{P},\tilde{Z},R) = a + B'\tilde{P} + E\tilde{Z} + FR, \tag{12}$$

which provide n-1 equations. The numeraire equation is obtained from

[9]Similarly, a longrun Hicksian demand may be obtained from the unrestricted profit function (Lopez, 1984).

$$X_1/Z_1 = \tilde{\pi}(\tilde{P},\tilde{Z},R) - \sum_{i=2}^{n} \tilde{P}_i \tilde{X}_i, \tag{13}$$

$$X_1/Z_1 = a_0 + b'\tilde{Z} + c'R - 0.5\tilde{P}'B\tilde{P} + 0.5\tilde{Z}'C\tilde{Z} + 0.5R'DR. \tag{14}$$

Shortrun Marshallian elasticities are obtained by calculating first the derivatives for the $\tilde{X}$ equations. Other elasticities are derived from decomposition equations. Longrun elasticities require the optimum $\tilde{Z}$, which is obtained by solving for $\tilde{Z}$ in the expression

$$\tilde{W} = W/P_1 = \nabla_{\tilde{Z}}\tilde{\pi}(\tilde{P},\tilde{Z},R) = b + E'\tilde{P} + C\tilde{Z}. \tag{15}$$

The derivatives of $\tilde{Z}$ with respect to $\tilde{W}$ and $\tilde{P}$ can be obtained from equation 15. The results are $\partial\tilde{Z}/\partial\tilde{P} = -C^{-1}E$ and $\partial\tilde{Z}/\partial\tilde{W} = C^{-1}$. This allows the calculation of longrun elasticities for the quasi-fixed factors. The longrun elasticities for the variable factors are obtained from the decomposition equations.

Linear homogeneity is imposed by normalization, and symmetry is imposed by sharing of parameters. Monotonicity is verified when the predicted X's have the correct sign (that is, negative for variable inputs and positive for outputs). Curvature conditions are satisfied if the restricted profit function is a saddle function, convex in prices and concave in the quasi-fixed inputs. The Fuss-quadratic normalized profit function $\tilde{\pi}$ is globally convex in prices if the Hessian $\nabla^2_{pp}\,\tilde{\pi}(\tilde{P},\tilde{Z},R) = B$ is positive semidefinite and $\tilde{\pi}$ is globally concave in Z if C is negative semidefinite. In this study, curvature conditions are imposed following the Bayesian approach. The initial (unconstrained) parameter estimates are obtained by the iterative seemingly unrelated regression (ITSUR) technique, which is asymptotically equivalent to maximum likelihood estimation. Given that homogeneity and symmetry are maintained and monotonicity is verified, the mean of the posterior density—that is, the mean vector of those replications that satisfy the curvature conditions (nonnegative eigenvalues for B, nonpositive for C)—provides the estimates of the parameter vector. A total of 14,000 replications are carried out for Illinois and 7,000 for Indiana.

The desire to specify a highly disaggregated model in terms of outputs and/or inputs is often hampered by multicollinearity and degrees of freedom limitations. Thus, separability and nonjointness assumptions are usually maintained. In some cases, separability assumptions are not tested. More often, researchers maintain some separability assumptions in their models, and they test (and usually reject) separability at a higher level of aggregation than that of their models. For this study, we draw on recent empirical evidence (Lim and Shumway, 1989b) that finds that consistent aggregation of all outputs in a single category is justified in several of the 48 contiguous States, including Illinois and Indiana. The model is specified as part of a two-stage optimization (Fuss). The output submodel is a revenue function that includes five output categories. The input submodel includes aggregate output and nine input categories: hired labor (numeraire), feed, seeds, fertilizer, pesticides, fuels, capital and related services, operator/unpaid family labor, and land (including buildings). Operator/family labor and land are considered as quasi-fixed. The model also includes time as a proxy for disembodied technical change, a weather index that is discussed in the next section, and a government policy variable to account for diversion payments.

The estimated model consists of eight equations obtained by appending additive disturbances to equations 12 and 14 to reflect errors in optimization. After symmetry and linear homogeneity are imposed, 61 parameters are estimated (that is, Θ is a 61-dimensional vector). After the parameters are estimated, SR Marshallian elasticities are calculated, and the decomposition equations are used to retrieve Marshallian LR and Hicksian SR/LR elasticities. Finally, the Morishima elasticities of substitution are obtained by using $(MES)_{ij} = \varepsilon_{ij} - \varepsilon_{jj}$.

The Data

The model is estimated using annual data for Illinois and Indiana for 1950-86. The data set used was compiled by Evenson and updated by McIntosh and Shumway (1989). The Evenson data set contains State-level annual observations of agricultural output and input expenditures, quantities and/or prices for the period 1949-82. Outputs include corn, sorghum, soybeans, oats, barley, wheat, rice, apples, grapes, oranges, grapefruits, hay sold, cotton, cottonseed, peanuts, lettuce, onions, tomatoes, potatoes, tobacco, sugar cane, sugar beets, edible beans, other crops, cattle and calves, hogs and pigs, sheep and lambs, milk, broilers, turkeys, eggs, and other livestock. Inputs include hired labor, unpaid operator and family labor, seeds, feeds, fertilizer, land, capital, and miscellaneous inputs. The Evenson data set was compiled using as primary sources the following USDA publications: *Agricultural Prices, Agricultural Statistics, Economic Indicators of the Farm Sector: State Financial Summary, Crop Production, Crop Values, Farm Labor, Meat Animals: Production, Disposition, and Income, Milk: Production, Disposition, and Income, Poultry Production and Value, Turkeys: Production, Disposition, and Gross Income, Farm Real Estate Market Developments* (USDA). The construction of these series is described in *Major Statistical Series of the U.S. Department of Agriculture* (USDA).

For this study, a fuel data series is added, and other minor changes are introduced. Fuel expenditures are obtained from *Economic Indicators of the Farm Sector* (USDA) and prices are from *Agricultural Prices* (USDA). For those years for which State-level fuel prices are not available, regional (Corn Belt) or U.S. prices are used as proxies. All aggregation is made using Tornqvist indexes.

Producers are assumed to make their production plans based on subjective evaluations of future output prices and government programs. Lagged output prices are used as proxies, based on results by McIntosh and Shumway, which show that one-period lags of output prices are better predictors of output price than other ARIMA models or futures-based models. To incorporate government programs in price expectation formation, the concepts of effective support price (ESP) (Houck and Subotnick; Houck and Ryan) and effective diversion payments (EDP) (Ryan and Abel) are convenient. The ESP is equal to the target price or "announced support rate" (PA) multiplied by an adjustment factor ($0 \leq = r \leq 1$) that represents the acreage restrictions imposed for obtaining the support price. Thus, ESP $= r \cdot PA$, and no restrictions imply $r = 1$. The EDP equals the payment rate per unit yield (PR) times a factor that accounts for the proportion of the acreage eligible for diversion (w). Thus, EDP $= w \cdot PR$. The ESP and EDP concepts are used in this study following Shumway and his collaborators (Shumway and Alexander; McIntosh and Shumway). Since announced government programs may affect farmers' decisions even when the ESP is below the expected output price (Shumway, McIntosh, and Polson), a weighted average of expected market prices and ESP is calculated using Romain's technique, in which the weights depend on the relative magnitudes of ESP, expected market prices, and loan rates.

While weather has been recognized as a very important factor in the supply of agricultural commodities, few empirical studies using the dual framework have incorporated weather into their models. Shumway used the Stallings index, which is the ratio of actual to calculated yields based on a linear trend. A drawback of the Stallings index is that it is not directly related to weather variables. More recently, Shumway and Alexander and McIntosh and Shumway have directly incorporated weather variables (such as rainfall and temperature in critical planting and growing months) in their dual models. However, they report statistically insignificant weather coefficients. One difficulty with this direct approach is that it consumes scarce degrees of freedom because it introduces many additional variables into the model. This study introduces into the model a weather index, R_2, that synthesizes the weather information relevant to each specific crop in a given location. The index is defined as the ratio of actual to normal yields and is calculated for each major crop as a function of the weather variables V_i :

$$R_2 = \frac{Y_{actual}}{Y_{normal}} = 1 + \frac{1}{Y_{normal}}(\sum_{i=1}^{n} \beta_i V_i). \tag{16}$$

The coefficients β_i are calculated using Thompson's multiple-regression technique (Thompson, 1970, 1986) to capture the effect of weather on yields, using State-level yield (*Agricultural Statistics*, USDA) and weather (Teigen and Singer) data. Following Thompson, the relevant weather variables for the Corn Belt are preseason precipitation, June, July, and August rainfall, June, July, and August temperature (all in deviation form), and their squares.

Empirical Results

Table 3 compares the SR Marshallian own-price elasticity for the variable inputs for Illinois in 1986, with and without imposing curvature conditions. Theoretically consistent own-price elasticities are larger in absolute value than the corresponding unrestricted elasticities and differences range from about 9 percent for hired labor to 64 percent for pesticides. For Indiana, the differences range from less than 4 percent for fuels to 63 percent for hired labor, excluding the supply elasticity, which is slightly negative in the case that convexity is not imposed (table 4).

Tables 5 and 6 present the SR Marshallian and Hicksian elasticities for the last observation (1986) for Illinois and Indiana. Tables 7 and 8 include the corresponding LR Hicksian elasticities. Table 9 summarizes the estimated own-price Hicksian and Marshallian elasticities for fertilizer and pesticides in the short run and long run for Illinois and Indiana. As expected, all own-price elasticities are negative for inputs and positive for outputs, and Le Chatelier's principle is satisfied in both the LR/SR case and the Marshallian/Hicksian case. All elasticities are in the inelastic range except for hired labor. The results of tables 5 and 6 show that in the short run, except for feeds, the difference between the Marshallian and Hicksian elasticities is very small, due to a small shortrun expansion effect in both States. This effect is larger in the long run. Compared with the results of this paper, Lopez (1984) finds moderate longrun expansion effects in Canadian agriculture, while Higgins finds large effects for Irish agriculture. The signs of the cross-price input demand elasticities are often used to classify inputs into net (gross) substitutes when the Hicksian (Marshallian) elasticity is positive or net (gross) complements when negative. The classification into net and gross substitutes/ complements coincides for all pairs for Illinois (table 5) and most pairs for Indiana (table 6). In the short run, all pairs are weak substitutes/complements in Illinois, except for the hired labor/capital pair, although this weakness is moderated in the long run (tables 5 and 7). Nearly 60 percent of Illinois' pairs are shortrun substitutes, and about 70 percent are longrun substitutes. In both the short run and long run, pesticides behave as a net and gross substitute for feeds, fertilizer, fuel, and capital, while fertilizer is a net and gross substitute for feeds and pesticides. The substitutability between pesticides and fuel and between pesticides and capital may be related to alternative tillage practices, while the substitutability between feeds and fertilizers, feeds and pesticides, and feeds and other inputs may be due to the effect of purchased feeds. The results for Indiana show a similar pattern, and analogous comments apply (tables 6 and 8). However, there are substantial differences in the numerical values of some elasticities (in particular hired labor) between Illinois and Indiana, confirming the results of other findings (such as, Shumway and Alexander) that differences in production structure across States can

Table 3—Own-price shortrun Marshallian elasticities with and without a theoretically consistent restricted profit function, Illinois, 1986

Input	Own-price elasticities		Percent difference
	With	Without	
Hired labor	-2.076	-1.884	9.2
Feeds	-.242	-.134	44.6
Seeds	-.291	-.255	12.4
Fertilizer	-.078	-.065	16.7
Pesticides	-.104	-.037	64.4
Fuels	-.048	-.039	18.8
Capital	-.601	-.487	19.0
Output	.061	.032	47.5

Table 4—Own-price shortrun Marshallian elasticities with and without a theoretically consistent restricted profit function, Indiana, 1986

Input	Own-price elasticities		Percent difference
	With	Without	
Hired labor	-0.776	-0.286	63.1
Feeds	-.155	-.087	43.9
Seeds	-.268	-.273	1.9
Fertilizer	-.076	-.099	30.3
Pesticides	-.082	-.097	18.3
Fuels	-.164	-.158	3.7
Capital	-.261	-.179	31.4
Output	.017	-.009	152.9

be substantial.[10] In view of their theoretical limitations, Allen-Uzawa ES will not be reported. Also, since AUES carries the same sign of the cross-price elasticity, the definitions of Allen and net complementarity/substitutability coincide.

As to the chemical inputs (table 9), the estimated own-price SR elasticities of fertilizer (-0.07 to 0.08) lie at the lower end of the range of previous econometric estimates using dual models (for example, table 2), while own-price LR Marshallian estimates (-0.16 to -0.76) are in line with previous estimates. The results are consistent with the estimates for nitrogen fertilizers for 1980-89 by Vroomen and Larson using a direct approach and are also similar to estimates for the United Kingdom by R. England and for West Germany by Berg based on linear programming techniques (Burell). The demand for pesticides (table 9) is also quite inelastic (own-price elasticities between -0.08 and -0.10 in the short run and between -0.4 and -0.6 for the LR Marshallian), but there is little published information with which to compare our results. Earlier research (Miranowski)

[10]A possible reason for the differences between the elasticities of hired labor in Illinois and Indiana may be the differences in opportunities for off-farm labor (such as, the number of large urban centers located near the farms in the State). In general, differences in production structure may occur due to weather, soils, and socioeconomic conditions.

Table 5—Marshallian/Hicksian shortrun elasticities of input demand, Illinois, 1986

Input	With respect to the price of— Hired labor	Feeds	Seeds	Fertilizer	Pesticides	Fuels	Capital
Hired labor:							
Marshallian	-2.076	-0.166	0.154	-0.091	-0.149	-0.282	2.878
Hicksian	-2.035	-.308	.146	-.117	-.136	-.291	2.741
Feeds:							
Marshallian	-.028	-.242	.029	.027	.017	.013	.027
Hicksian	-.052	-.159	.033	.042	.010	.018	.108
Seeds:							
Marshallian	.135	.149	-.291	-.051	-.075	-.025	.113
Hicksian	.128	.173	-.290	-.046	-.077	-.024	.136
Fertilizer:							
Marshallian	- .041	.071	-.026	-.078	.072	-.017	- .057
Hicksian	-.052	.111	-.024	-.070	.068	-.015	-.018
Pesticides:							
Marshallian	-.100	.069	-.057	.107	-.104	.111	.030
Hicksian	-.091	.039	-.059	.102	-.101	.109	.001
Fuels:							
Marshallian	-.233	.061	-.024	-.032	.138	-.048	.088
Hicksian	-.240	.088	-.022	-.027	.135	-.047	.114
Capital:							
Marshallian	.423	.024	.019	-.019	.007	.016	-.601
Hicksian	.403	.093	.023	-.006	.000	.020	-.533

reports price elasticities of -0.19 for herbicides and -0.62 for insecticides in the production of corn, based on 1966 cross-sectional data.

Tables 10 and 11 present the shortrun and longrun Morishima elasticities of substitution (MES) for 1986 for Illinois and Indiana. For most inputs, the differences in MES between the short run and the long run are small except for some of the input pairs that involve hired labor or capital. The estimates for Illinois also show that, while less than 60 percent of the input pairs behave as net (Allen) substitutes, more than 90 percent of the input pairs exhibit SR Morishima substitutability. This behavior, which also occurs in Indiana, was first noted by Ball and Chambers in a different context. Strong Morishima substitutability is found for the hired labor/capital pair, in both the short run and long run. The large degree of asymmetry for that pair also suggests that any policy that causes similar percentage decreases in the price of capital or increases in the price of hired labor will induce very different increases in the capital/hired-labor ratio. For example, in Illinois, a 10-percent increase in the price of hired labor will lead to an 11-percent increase in the longrun capital/labor ratio. However, a 10-percent decrease in the price of capital would lead to a 148-percent increase in the capital/labor ratio. All other pairs show much weaker SR and LR Morishima complementarity. For example, a 10-percent increase in the price of pesticides will increase the fertilizer/pesticide ratio by only about 2 percent. The inherent asymmetry of the Morishima elasticities is very pronounced in both the short run and long run. Only four input pairs exhibit a small to moderate degree of asymmetry in Illinois. They are fertilizer/feeds, pesticides/fuels, capital/seeds, and feeds/pesticides. The asymmetry in the

Table 6—Marshallian/Hicksian shortrun elasticities of input demand, Indiana, 1986

Input	With respect to the price of—						
	Hired labor	Feeds	Seeds	Fertilizer	Pesticides	Fuels	Capital
Hired labor:							
Marshallian	-0.776	-0.301	0.153	-0.023	-0.116	-0.212	1.090
Hicksian	-.697	-.187	.171	.012	-.126	-.206	1.032
Feeds:							
Marshallian	-.050	-.154	.022	.038	.030	.011	.059
Hicksian	-.031	-.127	.027	.046	.028	.012	.046
Seeds:							
Marshallian	.174	.153	-.268	.007	-.100	-.093	.078
Hicksian	.195	.182	-.263	.016	-.102	-.091	.063
Fertilizer:							
Marshallian	-.011	.111	.003	-.076	.009	-.001	-.075
Hicksian	.006	.135	.007	-.068	.007	.000	-.088
Pesticides:							
Marshallian	-.106	.165	-.079	.017	-.082	.064	.041
Hicksian	-.115	.152	-.081	.013	-.081	.064	.048
Fuels:							
Marshallian	-.210	.065	-.080	-.002	.070	-.164	.307
Hicksian	-.204	.074	-.079	.001	.069	-.164	.303
Capital:							
Marshallian	.180	.059	.011	-.025	.007	.051	-.261
Hicksian	.170	.045	.009	-.029	.009	.050	-.254

fuels/capital pair noted by Taylor and Gupta for southeastern agriculture is even more pronounced for Illinois but not for Indiana.

Model Simulations

An unintended side effect of agricultural producers' activities is the nonpoint pollution of ground and surface water from fertilizers and pesticides, imposing a cost to society often not fully accounted for in farmers' decisions. Two market-oriented strategies intended to reduce the use of chemical inputs are the imposition of ad valorem taxes on fertilizers and pesticides and a reduction of the government agricultural supports. This section examines the effect of these strategies, using the empirical model.

Taxes on fertilizers and pesticides can be used to internalize environmental costs not reflected in market prices. If they faced higher chemical prices, farmers would reduce their use of these inputs. The extent of the farmers' responsiveness is provided by the elasticities of input demand. Higher fertilizer prices induce farmers to improve monitoring techniques (for example, soil testing) and/or sacrifice yields to reduce fertilizer use. Higher pesticide prices induce substitution. For example, mechanical tillage is a substitute for herbicides, which make up 92 percent of the pesticides used in the Corn Belt (Osteen and Szmedra). In addition to reducing chemical input use, tax revenue

Table 7—Hicksian longrun elasticities of input demand, Illinois, 1986

Input	With respect to the price of—							
	Hired labor	Feeds	Seeds	Fertilizer	Pesticides	Fuels	Capital	Land
Hired labor	-11.450	0.090	0.150	-0.062	-0.287	-0.264	3.383	8.442
Feeds	.015	-.191	.033	.038	.022	.016	.056	.011
Seeds	.132	.171	-.290	-.047	-.076	-.024	.133	.001
Fertilizer	-.028	.100	-.024	-.072	.072	-.015	-.037	.004
Pesticides	-.191	.086	-.058	.108	-.119	.113	.078	-.016
Fuels	-.218	.077	-.022	-.028	.139	-.048	.097	.004
Capital	.497	.049	.022	-.012	.017	.017	-.605	.015
Land	-.044	.021	.000	.003	-.008	.001	.034	-.007

Table 8—Hicksian longrun elasticities of input demand, Indiana, 1986

Input	With respect to the price of—							
	Hired labor	Feeds	Seeds	Fertilizer	Pesticides	Fuels	Capital	Land
Hired labor	-12.030	-0.224	0.165	0.004	-0.116	-0.206	1.077	11.33
Feeds	-.037	-.140	.025	.043	.031	.012	.060	.005
Seeds	.188	.169	-.266	.013	-.099	-.091	.079	.006
Fertilizer	.002	.127	.006	-.070	.010	.000	-.078	.004
Pesticides	-.105	.170	-.079	.018	-.086	.064	.025	-.008
Fuels	-.204	.073	-.079	.000	.070	-.164	.304	.000
Capital	.178	.060	.011	-.026	.005	.051	-.271	-.006
Land	.003	.007	.001	.002	-.002	.000	-.008	-.003

Table 9—Own-price elasticities of chemicals, central Corn Belt, 1986

Input/State	Shortrun Hicksian	Shortrun Marshallian	Longrun Hicksian	Longrun Marshallian
Fertilizer:				
Illinois	-0.070	-0.078	-0.072	-0.155
Indiana	-.068	-.076	-.070	-.760
Pesticides:				
Illinois	-.101	-.104	-.119	-.382
Indiana	-.081	-.082	-.086	-.604

Table 10—Shortrun and longrun Morishima elasticities of substitution, Illinois, 1986

Input	Hired labor	Feeds	Seeds	Fertilizer	Pesticides	Fuels	Capital
Hired labor:							
SR	—	1.72	2.18	1.92	1.90	1.74	4.77
LR	—	11.50	11.60	11.40	11.20	11.20	14.80
Feeds:							
SR	0.11	—	.19	.20	.17	.18	.27
LR	.21	—	.22	.23	.21	.21	.25
Seeds:							
SR	.42	.46	—	.24	.21	.27	.43
LR	.92	.46	—	.24	.21	.27	.42
Fertilizer:							
SR	.02	.18	.05	—	.14	.06	.05
LR	.04	.17	.05	—	.14	.06	.04
Pesticides:							
SR	.01	.14	.04	.20	—	.21	.10
LR	-.07	.21	.06	.23	—	.23	.20
Fuels:							
SR	-.19	.13	.02	.02	.18	—	.16
LR	-.17	.12	.03	.02	.19	—	.14
Capital:							
SR	.94	.63	.56	.53	.53	.55	—
LR	1.10	.65	.63	.59	.62	.62	—

— = Zero (all diagonal values are zero by definition). SR = Short run. LR = Long run.

collected may be used to pay for water monitoring and for research in alternative production technologies that may further reduce chemical input use.

The responsiveness of the demand for fertilizers to an ad valorem tax is very limited in the Corn Belt States. For example, in Illinois, a 10-percent reduction in fertilizer applications would require a 128-percent tax in the short run and a 65-percent tax in the long run.[11] In Indiana, the situation is similar in the short run but less extreme in the long run: a 10-percent reduction in fertilizer use would require a 132-percent tax in the short run and a 13-percent tax in the long run. Hallberg cites evidence indicating that seldom is more than 70 percent of the nitrogen fertilizer applied recovered in agronomic crops. Residual nitrogen that results from overfertilization is lost in several ways, including leaching into the ground water and runoff to surface water. From an environmental point of view, fertilizer application need not be reduced beyond what is necessary to attain a negligible level of fertilizer available for leaching or runoff. Thus, an upper limit for the reduction in fertilizer application is provided by the residual nutrient.[12] Huang and Lantin estimate the residual nitrogen

[11]The results of this section are only approximate and should be viewed with caution because (1) point elasticities are assumed to be approximately applicable, (2) feedback output effects are not considered since this model examines only the supply of output, and (3) the data do not capture the structural change that must have resulted from the changes in policy introduced in recent years.

[12]Residual nutrient is defined as the difference between the amount of nutrient applied from all sources on an acre of cropland and the amount removed at the end of the growing season in the grain and stalks. Huang and Lantin called this concept excess nutrient.

Table 11—Shortrun and longrun Morishima elasticities of substitution, Indiana, 1986

Input	Hired labor	Feeds	Seeds	Fertilizer	Pesticides	Fuels	Capital
Hired labor:							
SR	—	0.51	0.87	0.71	0.57	0.49	1.73
LR	—	11.80	12.20	12.00	11.90	11.8	13.10
Feeds:							
SR	0.10	—	.15	.17	.16	.14	.17
LR	.10	—	.16	.18	.17	.15	.20
Seeds:							
SR	.46	.45	—	.28	.16	.17	.33
LR	.45	.43	—	.28	.17	.17	.34
Fertilizer:							
SR	.07	.20	.08	—	.08	.07	-.02
LR	.07	.20	.08	—	.08	.07	-.01
Pesticides:							
SR	-.03	.23	-.00	.09	—	.14	.13
LR	-.02	.26	.01	.10	—	.15	.11
Fuels:							
SR	-.04	.24	.09	.16	.23	—	.47
LR	-.04	.24	.08	.16	.23	—	.47
Capital:							
SR	.42	.30	.26	.22	.26	.30	—
LR	.45	.33	.28	.25	.28	.32	—

— = Zero (all diagonal values are zero by definition). SR = Short run. LR = Long run.

associated with the production of corn to be about 110 pounds per acre per year. Since the average amount of nitrogen used on corn in 1986 was 155 pounds per acre in Illinois and 149 pounds per acre in Indiana (Vroomen), the reduction in nitrogen fertilizer applications needed to achieve a zero residual nutrient in Illinois would require a tax of more than 300 percent in the short run and nearly 200 percent in the long run. In Indiana, a cutback in nitrogen fertilizer use to reach a zero residual nutrient would need a tax of more than 400 percent in the short run and 50 percent in the long run. The calculated shortrun responsiveness of nitrogen fertilizer demand in the central Corn Belt to a nitrogen fertilizer tax appears to be in line with results for the European Community (EC), where the per acre application of fertilizer is more than twice that of the United States. A 400- to 500-percent tax on nitrogen would be required in the EC to achieve a "noticeable effect," according to Henrichmeyer.

The demand for pesticides in the central Corn Belt (mostly herbicides) is similarly unresponsive to a tax in the short run but less so in the long run. A 10-percent reduction in pesticide use in Illinois would require a 96-percent pesticide tax in the short run and a 26-percent tax in the long run. For Indiana, a 10-percent reduction would be achieved with a 123-percent pesticide tax in the short run and a 17-percent tax in the long run. Thus, even moderate reductions in fertilizer or pesticide use would require substantial taxes, particularly in the short run. On the other hand, the shortrun effect of taxes on farm income is important. A simple calculation shows that in Illinois the tax necessary to achieve a 10-percent reduction in fertilizer use in the short run would cause a 41-percent drop in farm income, while the tax required to decrease pesticide use by 10 percent would reduce income by 17 percent. In Indiana, the shortrun drop in income would be 67 percent for a 10-percent reduction in fertilizer use and a 33-percent income drop for a 10-percent reduction in the use of pesticides.

For more than 50 years, Federal farm programs have played a key role in farmers' decisions and, consequently, in the supply of a large portion of U.S. agricultural output. As Gardner observes, "attempts to support prices above market-clearing levels have been a characteristic of U.S. farm-commodity policy since the 1930's." Support prices were reduced in real terms during the 1960's and 1970's, and supplemented by deficiency payments, whereby farmers receive from the government the difference between the target and the larger of the market prices or loan rate. In addition, most grain acreage is eligible for reduction programs that induce farmers to divert land away from the supported crop by idling the land or using it for certain restricted uses. Farmers who participate receive payments for part of the required acreage diversion, while nonparticipating farmers become ineligible for deficiency payments or CCC (Commodity Credit Corporation) loans. Agricultural supports are concentrated on a few crops (like corn, soybeans, wheat, and cotton) that use at least 65 percent of all chemical inputs (Fleming). The Corn Belt received more than 30 percent of the government supports in 1988 (*Economic Indicators of the Farm Sector*, USDA).

Over the last several decades, such agricultural supports have tended to increase the use of chemical inputs for two major reasons: first, they have been tied to the production level, which stimulated the increase of total crop production, and, second, they encouraged more intensive production (Fleming). Although the freezing of program yield levels has lessened these effects and made the causation less direct, support programs still effectively raise output price above market levels (Crutchfield). Supports are also believed to discourage crop rotations and other low-input techniques, since only a few crops are covered by the programs. However, the triple-base option of the 1990 farm legislation will reduce these latter effects in the long term.

It is not generally efficient to use an output policy to reduce or eliminate the environmental damage resulting from an externality associated with the use of an input. However, government agricultural output supports have already introduced economic inefficiencies. Restructuring some Federal programs by reducing their incentives for added production and reducing current supports not only would contribute to improved environmental quality by decreasing chemical input use but also would contribute to moving the agricultural sector towards increased economic efficiency by reducing market distortions. If the pertinent Federal supports are reduced, say, to the equivalent of a 10-percent decrease in the (effective) output price faced by farmers,[13] output in Illinois would decline slightly (by less than 1 percent) in the short run and by 26 percent in the long run. At the same time, fertilizer use would decline slightly in the short run and by 16 percent in the long run. Pesticide use would essentially remain unchanged in the short run and decrease 36 percent in the long run. In Indiana, the shortrun effects of a reduction by 10 percent in the effective output price are even smaller than in Illinois, but the longrun effects are larger: fertilizer use would decrease by 72 percent and pesticides by 85 percent. In the long run, a 10-percent reduction in fertilizer use requires a decline in effective output prices of 6 percent in Illinois and less than 2 percent in Indiana. Corresponding reduction percentages in output price for a 10-percent drop in pesticide use are 3 percent for Illinois and about 1 percent for Indiana. If agricultural supports are decreased to a level such that output prices faced by farmers drop by 10 percent, fertilizer use in Indiana would be reduced in the long run to a degree that approximately reaches zero excess nutrient. In Illinois, a similar reduction would not lead to zero excess nutrient. Fertilizer intensity would be about halfway between the current level and the level corresponding to zero excess nutrient. Finally, the reduction in chemical input use stemming from

[13]Current support programs for major grains (deficiency payments and nonrecourse loans) amount to more than 10 percent of the revenues, adjusting for land-use restrictions.

diminished agricultural supports reported here is subject to the qualifications indicated earlier (see footnote 9).

Concluding Comments

This study provides a procedure whereby, based on estimation of a theoretically consistent restricted profit function and using a series of decomposition equations, all demand functions (Hicksian and Marshallian in the short run and long run) are readily calculated. Unlike previous work, this study simultaneously imposes convexity in prices and concavity in quasi-fixed factors. Both curvature properties are essential in the use of decomposition methods to avoid violations of Le Chatelier's principle. In addition to four types of price elasticities, both the Allen-Uzawa and Morishima ES can be calculated without estimating the cost function, although theoretical evidence favors the use of the Morishima elasticities. Thus, the proposed methodology can provide a large amount of information to facilitate the analysis of the flexibility of production systems. The model is disaggregated in the input side to provide information (for example, on pesticides) not readily available from models of this type, and also includes a new weather index.

More empirical work is needed using dual models with a fair amount of disaggregation in the input side. While these efforts are facilitated by the use of two-stage modeling, some separability and homotheticity assumptions still need to be established. The task can be simplified by drawing on nonparametric results such as those of Lim and Shumway (1989a, 1989b). If the estimated model is theoretically consistent, all elasticities will be of the correct sign, and Le Chatelier's principle will be satisfied.

The responsiveness of central Corn Belt producers to price changes for fertilizers and pesticides is very small in the short run and small to moderate in the long run. This means that if input taxes were used to achieve moderate reductions in chemical use, substantial taxes would be needed, particularly in the short run.[14] However, while a reduction in government agricultural support programs also has a negligible shortrun impact, its longrun effect is larger than that corresponding to a similar percentage increase in the fertilizer or pesticide price. Estimating the welfare implications of taxes versus a reduction of agricultural supports is beyond the scope of the paper, but the advantages of pursuing policies that shift the agricultural sector towards a free market are well known. This paper provides support for the argument that, in the long run, such policies will be environmentally beneficial as well.

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[14]Thus, the impact of taxes at the levels imposed on fertilizers by some countries in Western Europe (25 percent) will be negligible in the short run and small to moderate in the long run.

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U.S. Department of Agriculture
Economic Research Service

SUMMARY OF REPORT

Production Costs for Ethanol to Drop as New Technology Comes On-Line

Number 7, February 1993

Contact: Neil Hohmann (202) 219-0428

The fuel ethanol industry is poised to adopt a wide range of technologies that would reduce costs at every stage of the production process. Adoption of improved enzymes, fermenter designs, membrane filtration, and other innovations in the next 5 years is expected in new ethanol plants constructed to meet new demand resulting from Clean Air Act stipulations for cleaner burning fuel. A new report, *Emerging Technologies in Ethanol Production*, examines the likelihood of near- and long-term cost reductions in producing ethanol, as well as the potential of biomass (agricultural residues, municipal and yard waste, energy crops like switchgrass) to supplement corn as an ethanol feedstock.

Ethanol Industry Expands, Reducing Costs

The use of ethanol as a fuel for vehicles in the United States grew from insignificance in 1977 to nearly 900 million gallons in 1991. The ethanol industry emerged through a combination of government incentives and new technologies, which enabled large-scale production of ethanol from domestic resources, particularly corn. Growing consumer acceptance of ethanol-blended fuels, incentives to gasoline blenders, and falling costs of production (from $1.35-$1.45 per gallon in 1980 to less than $1.25 per gallon in 1992) were responsible for the jump in ethanol production.

The construction of new ethanol production plants and the adoption of new technologies at existing plants is likely to lead to further cost reductions (5-7 cents per gallon over the next 5 years). Improved yeasts, which tolerate high concentrations of ethanol, can lower energy costs. A system of membranes can recycle enzymes and capture high-value coproducts at many steps in the production process.

Longer term technologies would save approximately 9-15 cents per gallon over present costs. Energy and feedstock savings will result from technology that can convert some of the nonstarch portions of corn to ethanol. Development of microorganisms that speed the process will contribute to long-term savings. Development of markets for coproducts of ethanol production will create additional savings. Cost savings may be less for smaller plants that serve niche markets, or in older plants that must replace inefficient equipment.

Ethanol From Biomass Reduces Costs and Environmental Waste

Biomass can also be converted to ethanol, although commercial-scale ventures are limited by current technology. While biomass requires more handling and sorting before conversion, those costs may be offset by the abundance of biomass relative to corn. Although the production of ethanol from biomass is presently constrained by technological difficulties, new developments in this decade may allow ethanol to be produced from biomass at or below the cost of corn-derived ethanol.

To Order This Report...

The information presented here is excerpted from ***Emerging Technologies in Ethanol Production,*** AIB-663, by Neil Hohmann and C. Matthew Rendleman. The cost is $9.00.

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U.S. Department of Agriculture
Economic Research Service

SUMMARY OF REPORT

Off-farm Income Is Critical to Most Farm Operator Households

Number 8, February 1993

Contact: Mary Ahearn, 202/219-0306

Farm household income, at $39,007 from both farm and off-farm sources in 1990, is on par with average U.S. household income, according to the Economic Research Service's *The Economic Well-Being of Farm Operator Households, 1988-90.*

The average off-farm income of farm operator households in 1990 was $33,265, or 85 percent of their total household income. Only $5,742 of the total income for farm operator households in 1990 was income from their farms. Most of the off-farm income comes in the form of wages and salaries. In about 60 percent of farm operator households, either or both the farm operator or spouse earned off-farm wage and salary income.

The new report is based on USDA's Farm Costs and Returns Survey.

Nearly three-quarters of farm households operate small farms with gross sales below $50,000. These households lose money on their farms on average. Another 22 percent of farms would still be considered of modest size, with gross sales of $50,000 to $249,999. In 1990, most of these households had a positive return from their farms, averaging $16,236. Only 6.2 percent of farms had sales of $250,000 or more in 1990. Although they are small in number, these larger farms produced just over half of the agricultural commodities in the United States in 1990. Farm households reporting sales in the $250,000 to $499,999 range averaged $53,314 from their farms, and those with sales above $500,000 averaged $118,035.

The receipt of off-farm income has become one of the most important means for farm operator households to diversify their financial position and bring greater security to the household. Only about 20 percent of farm operator households received more income from the farm than off the farm in 1990, although another 10 percent of farm households lost more on their farm than they made off their farm. Small farm households earned the largest off-farm incomes at $37,276, but the off-farm incomes of those with very large farms (with more than $500,000 in sales) were not much lower, at $32,698.

Income of farm operator households and all U.S. households, 1990

Average income of farm operator households is on par with that of all U.S. households.

Item	Farm operator households	U.S. households
Number	1,738,019	94,312,000
	Percent	
Household income class:		
Less than $10,000	22.2	14.9
$10,000 - $24,999	27.2	27.2
$25,000 - $49,999	28.8	33.3
$50,000 and more	21.8	24.6
Below poverty threshold	21.9	13.5[1]
	Average dollars	
Household income	39,007	37,403

[1] For U.S. persons. The poverty rate for U.S. families was 10.7 percent in 1990.

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The information presented here is excerpted from ***The Economic Well-Being of Farm Operator Households, 1988-90,*** AER-666, by Mary C. Ahearn, Janet E. Perry, and Hisham S. El-Osta. The cost is $15.00.

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U.S. Department of Agriculture
Economic Research Service

SUMMARY OF REPORT

Restricting Chemical Use on the Most Vulnerable Cotton Acreage Can Protect Water Quality With Only Minor Effects on Cotton Yields and Prices

Number 6, January 1993

Contact: Stephen R. Crutchfield, (202) 219-0444.

Environmental damage to surface and ground water posed by cotton farming may be reduced, with only limited effects on yields and prices, if restrictions on agrichemical use or production are applied to just those acres most vulnerable to water-quality problems. The most widespread potential damage is from nitrates in fertilizer that can pollute ground water and pesticides that can contaminate surface water.

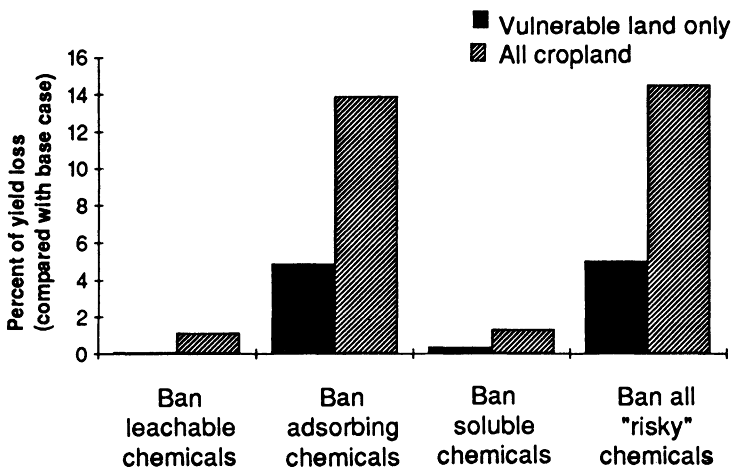
Production of cotton appears less likely than other crops to cause erosion-induced water-quality problems because cotton acreage is not the major source of cropland erosion in most regions. Widespread restrictions on the use of chemicals likely to leach, dissolve in cropland runoff, or attach to eroding soils may reduce the risk of water-quality degradation, but may also raise cotton prices by reducing yields. These conclusions flow from USDA's 1989 Cotton Water Quality Survey that gathered data on cotton agricultural chemical use and related production practices and resource conditions in 14 cotton States. Data gathered on the use of fertilizers, herbicides, insecticides, and other agricultural chemicals were analyzed to assess the potential water-quality problems that may be associated with cotton production.

Widespread Restrictions Could Raise Cotton Prices

The study's results highlight the importance of targeting pollution-prevention programs to attain the most cost-effective environmental protection strategies. Restricting the use of environmentally damaging chemicals on all cotton acreage could reduce the overall potential for water-quality impairment, but could raise cotton prices by as much as 31 percent. More specific chemical-use restrictions, targeted to acreage considered at greatest water-quality risk, could achieve nearly the same level of environmental protection, but would limit price increases and reduce yield losses. Modifying production practices to reduce soil erosion could generate $25 million in economic benefits by reducing sedimentation in surface water systems.

Yield losses from chemical restrictions on cotton acreage

Yield losses are minimized if chemical restrictions are targeted to only cotton acreage at greatest water-quality risk.



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